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Memo

Date: *Dec. 20, 2012 (Posted Dec. 22, 2014)*

To: *RSC*

From: *D. Beavis* DB *K. Kusche & P. Bergh*

Subject: ***ATF Shielding Verification via beam Fault Studies Summary***

Summary

A series of routine and beam fault measurements were conducted and analyzed which show that the ATF shielding is well designed to protect personnel from beam losses during routine and fault conditions. The beam loss locations were chosen to challenge the shielding design and validate locations that were not discussed in existing documentation (see LESHC meeting minutes of Oct. 22, 2012, http://www.c-ad.bnl.gov/LESHC/LESHC/LESHC%2012-09.pdf . The ATF is safe to operate with essentially no changes to its shielding and posting configuration.

Fault studies were conducted with single bunch operation at 70 MeV and scaled to 0.128 Watts (single bunch) and multi-bunch operation at 1.28 Watts. An energy of 40 MeV was used to demonstrate the shielding protected against over-current miss-steering by the large dipoles (20 Degree bends). The active radiation detectors are well placed to monitor several of the weak locations. The TLD monitor data when background subtracted are consistent with the low radiation levels detected during the fault studies and provide a working record of average low doses external to the shielding. Only minor changes are recommended for multi-bunch operations.

Introduction

There are many approaches that will meet and exceed the radiation protection standards for the areas at ATF. The ATF will begin operations with the adjacent areas configured with the posting shown in Table I. RCD procedure FS-SOP-3000 was used in determining the appropriate radiological postings for ATF areas. No additional shielding is required, but should be considered for the future improvement of the facility and multi-bunch operations. Essentially all changes for posting are to accommodate either weak locations and/or multi-bunch operations. The reader can refer to Figures 1a and 1b of the March 2010 ATF SAD for locations.

Table I: Areas and Postings

Area	Old or New	Present Posting	New Posting	comments
gun	Old	Controlled	Controlled	
Linac Tunnel	Old	Controlled-TLD required	Controlled	1
Hallway d/s of control room	Old	Controlled	Radiation Area-TLD Required	2
North area of control room	Old	uncontrolled	Controlled Area	
Mezzanine	New	Uncontrolled	Controlled	3
Experimental Hall	Old	Controlled	Controlled	4
Exp. Hall – near D2	New	Controlled	Radiation Area	5
CO2 & laser rooms on east side	Old	Controlled	Controlled	6
Outside North-west corner of exp. area	New	uncontrolled	Controlled	7
Roof over exp. area	Old	uncontrolled	Controlled-No entry with beam on	8
East wall beside linac tunnel	New	uncontrolled	uncontrolled	9
East area at end wall	New	uncontrolled	Controlled	10

1. There has been no residual activity in machine components that would require a TLD. After any long periods of multi-bunch operation residual surveys are suggested.
2. The area should be posted as a radiation area during multi-bunch operation if shielding is not added. A layer of borated poly would probably have a large impact on reducing the neutron dose rate. In addition the location and correlation of the chipmunk dose rates to the area dose rates could be used to reduce potential dose and the need to post as a Radiation Area.
3. The location of monitor TLDs should be checked to ensure they provide yearly dose rates for expected work area.
4. There is no evidence that there are any activation levels that would cause exposure to personnel. Similar to the Linac tunnel there should be residual activation measurements conducted after multi-bunch operations.
5. The area will be posted as a radiation area only with multi-bunch operations. The radiation monitor (chipmunk) dose rate should be correlated to the area dose and the

radiation area can then be appropriately limited in size. Administrative procedures can be added to have the beam turned off if the area is entered during multi-bunch operations.

6. The main concern will be dose near the gate. The chipmunk to area dose rates should be mapped and correlated.
7. This area will enclose the weak locations including the building penetrations of the shielding and the gap over the equipment door. A Controlled Area should not enclose the air handling equipment. Future improvements should consider reducing the gap over the equipment door.
8. Future routine and fault measurements should be conducted to allow unrestricted access. The levels are not expected to be high and work on the roof could be conducted with an RWP and appropriate monitoring, if necessary, before the measurements are conducted.
9. This area will remain uncontrolled. It was considered to be upgraded to a controlled area until it was determined that the monitor TLDs had not had the background dose subtracted.
10. The last section of the east end wall and building should be enclosed in a Controlled Area until monitor TLD data can be obtained. It is expected that TLD data will demonstrate that less than 25 mrem/yr occurs in this area. Dose rates outside could be correlated to the east gate chipmunk. It may be possible to add shielding to shadow this outside area and the east gate for ALARA.

Table II provides an index to the fault studies in the C-AD fault study log book. The surveys conducted by the RCTs can be found in the logbook.

Table II: ATF Beam Fault Studies

Area	Fault Study No.	Beam Energy (MeV)	Beam Power (W)	Fault Condition	Page RSC Logbook
Gun	CA-225	3.5 MeV	0.0053	Routine & Faraday Cup closed	72-82
Linac Tunnel	CA-226	70	0.095	Routine and penetrations	83-95
Linac Tunnel	CA-227	70	0.095	High Energy Slit	96-103
Linac Tunnel	CA-228	70 40	0.105 0.06	Miss-steering by D1	97-118
Experimental Area	CA-229	65	0.018	Routine BL1	119-134
Experimental Area	CA-229	65	0.04	Fault at SW corner and dipole miss-steering	135-140
Experimental Area	CA-229	65	0.027	Miss-steering by vertical bend	141-142
Experimental Area	CA-229	65	0.024	Routine BL2	143
Experimental Area	CA-229	65	0.035	Faults in BL2	144-149
Experimental Area	CA-229	40	0.028	Low Energy bending BL1 and BL2	150-151

Scaling and Modes of Operation

The fault studies were conducted at low beam power by keeping the beam current low. The beam energy for the Linac tunnel was typically 70 MeV. The vertical dipole in beam line one could not bend the 70 MeV the full 90 degrees so 65 MeV was chosen for the full energy studies in the experimental area. 40 MeV was chosen to examine miss-steering by large dipoles in both the Linac tunnel and the experimental area.

The ATF operates most of its program with a single beam bunch 1.5 times a second (1.5 Hz operations). The maximum beam power for single bunch operation is 0.128 Watts and 85 MeV. The ATF infrequently uses a multi-bunch mode in which several bunches are delivered with a repetition rate of 1.5 Hz. The maximum beam power for this mode of operation is 1.28 Watts at 85 MeV. An obsolete mode of operation which allows six Hz is prevented by mechanically locking the mode switch in the 1.5 Hz position.

The Gun (CA-225)

An HPI 1010 was used for the measurements near the gun vault. This instrument has a built-in quality factor of 5. Electrons at the gun energy and with the materials present cannot create neutrons and therefore the radiation field is exclusively x-rays. The fault study is documented on pages 72-82 of CA fault study logbook 1. The measurements presented on pages 80-82 have the quality factor of 5, which has been removed for the discussion in this report.

The first set of measurements was conducted with the laser off. The low x-rays dose rates are the result of "dark-current" from the various surfaces within the gun. The dose rates at 1 foot are typically less than 0.2 mrads per hour. The next set of radiation measurements had the laser excite the photocathode with the solenoids either on or off. The 3.5 MeV electron beam from the cathode strikes the closed Faraday cup, LPOP1, which is located after the solenoids. LPOP1 represents a total beam loss, but it may not be thick enough to be considered a thick target as implied by the curves used to estimate the possible x-ray levels outside the lead shield. The dose rate increased about 0.1 mrads per hour in some of the adjacent locations when the Faraday cup was struck. The beam current was 1 nano-C with a laser repetition rate of 1.5 Hz.

Linac Tunnel

Penetrations

The Linac tunnel has a series of penetrations. The dose rates are documented in this note for both routine operations and for fault conditions in Table III. The routine dose rates are then scaled to the routine limit of single bunch operation at 85 MeV and 1 nano-Coulomb per bunch at 1.5Hz which has a beam power of 0.128 Watts. Multi-bunch operation has additional bunches per cycle and has a maximum beam power of 1.28 Watts. The fault dose rates have been scaled for the maximum power for single bunch and multi-bunch operations. Table III shows the results from the studies. A small c after a number indicates it is a radiation measurement at contact. Otherwise, the numbers are at one foot from the surface. A small r after the dose rates are for locations in which the dose rate originates from the W-plug which is considered a routine mode of operation. All dose rates are measured with an HPI-1010, which has a built-in quality factor of 5. It will be assume that this is reasonable for the mixed radiation fields present.

The measured dose rates near the penetrations are quite low. Most of the dose rates are acceptable for an uncontrolled area, if it is not occupied full time. Penetration 3 has a routine dose rate of 0.14 mrem/hr, which is not desirable in an uncontrolled area. Most faults occurring near penetrations would be acceptable in a uncontrolled area or Controlled Area depending on the expected frequency and duration of such faults coupled with the expected occupancy. The highest scaled fault dose rate of 54 mrem/hr was measured outside penetration 3. With an active process to prevent fault duration for longer than fifteen minutes a dose of 14 mrem could be received by personnel one foot from the penetration. This area also has potential contributions from the high energy slit.

Table III: Routine and Fault Doses Rates Near Linac Tunnel Penetrations

penetration	Routine mrem/hr	Scaled Low Power routine mrem/hr	Single bunch (0.128W) Fault mrem/hr	Multi-bunch fault (1.28W) mrem/hr
Penetration 1	<0.05	<0.067	0.4	4.0
Penetration 2	<0.05c	<0.067	0.67	6.7
Penetration 3	0.1	0.14	5.4	54
Penetration 4	0.05	0.067	2.0	20
Modulator penetration	<0.05c	0.067	0.35	3.5
x-band pene.	.05c	0.067c	0.47	4.7
North Mezz. Penetration	0.3	0.41	0.41r	4.1r
Building-I beam	0.35c	0.47c	0.47c,r	4.7c,r
Building-wall mid way	0.125c	0.17c	0.17c,r	1.7c,r
Concrete door crack	<0.05	<0.067c	1.1	11

High Energy Slit (HES)

The high energy slit is located between the dipole D1 and the W-plug. Measurements were made with the slit fully open and then fully closed. It is not useful to operate the slit fully closed but there are no limitations to prevent it. The slit is used to remove the tails of the beam and in some cases substantially reduce intensity. The intensity of the beam can also be reduced by changing the laser power. From an ALARA point of view this would be the preferred method. However, it will be considered routine to have the slit essentially fully closed as a conservative approach.

The HES is located near a thin section of the west-side wall and relatively close to the fourth penetration. The radiation measurements have the beam stop in the W-plug. Leakage from the W-plug will contribute to the measurements. Table IV has the dose rates at several locations one foot from the west wall. The dose outside the shield wall will be dominated by the slit when the slits intercept a substantial portion of the beam, even if the W-plug is closed. When operating for experiments chronic low level leakage through the shield wall is most likely the result of beam intercepted by the adjustable slit. TLD 150 (formerly 78) has shown elevated dose rates. The integrated dose on TLD150 for 2011 was 250 mrem with most of the dose resulting from neutrons. It is not proven but the most likely culprit for the dose is the HES. TLD 360 in the north end of the control room registered 15 mrem for the same year. It appears that the increased distance and concrete block wall between TLD 150 and TLD 360 provides substantial dose reduction for the north end of the control room. For multi-bunch operations the dose rates would make the end of the hallway a Radiation Area if shielding is not added and the slit is intercepting at least 15% of the beam.

Table IV: HES Dose Rates in Hallway

Location	Routine dose rate Slit open (mrem/hr)	"routine" .128W dose rate Slit closed (mrem/hr)	1.28 Watt dose rate Slits closed (mrem/hr)
End of wall	0.27	0.81	8.1
Mid-pt on wall	0.7	3.	30
Penetration 4	0.14	5.	50

Tunnel Walls and the W-Plug

During the fault studies, locations along the tunnel wall were measured under routine and fault conditions. The east wall had dose rates below the minimum detectable level of 0.05 mrem/hr. The highest scaled dose rate one foot from the wall was 0.54 mrem/hr. During multi-bunch operation a fault dose could be 5.4 mrem/hr. The highest dose rate was near the concrete door crack, which is shown in Table III.

There is leakage on the wall into the CO2 room and the front end of the experimental Hall near bending magnet D2. Both of these areas have a chipmunk radiation detector to alert local personnel and the Linac operator in the control room if the radiation levels become elevated. The scaled dose rates for single and multi-bunch operation are given in Table V.

Table V: Dose rates with Beam on W-Plug

Location	Single bunch mrem/hr	multi-bunch mrem/hr
Near D2 in exp. area	4.	40
At corner in CO2 room	0.14	1.4

The front of the beam line near D2 is often not accessed by experimenters. A small area near D2 will be classified as a Radiation Area with TLD required for multi-bunch operations. With detailed measurements and additional administrative controls the Radiation area can be limited in extent. The experimental hall should be posted either as a Controlled Area or Controlled Area-TLD required.

D1 Miss-steering

Several currents were used on D1 to miss-steer 70 MeV electron Beam. 40 MeV was also used at full magnet current since this provides a fault that cannot be achieved at 70 MeV. Lower energies were not chosen since it was considered difficult to achieve a stable beam with energies much below 40 MeV. There was only one location that showed radiation levels greater than measured in other fault conditions. The scaled dose rate in the downstream section of the mezzanine was 2.8 mrem/hr (0.128W). For multi-bunch mode this fault would be 28 mrem/hr. The area will be changed to a Controlled Area.

Experimental Hall

The goal of the fault studies for the experimental hall was to examine penetrations, the end wall, and severe dipole miss-steering. Measurements on the building roof were not conducted due to access issues to the roof. The roof will be posted as a Controlled Area and access will not be allowed with beam on. Measurements on the roof will be taken at a later date. The dose rates were much lower than the estimates made before the fault studies were conducted. Some shielding was added prior to the studies rather than conduct studies multiple times.

The dose rates for routine operations and the fault conditions included both the losses from the beam transport and the fault condition. The percentage of beam transported to the end of the two beam lines ranged from between 36% and 92%. All dose rates are scaled by the delivered beam power to the operational beam power limits. This is a conservative scaling for the routine and fault conditions as the delivered power is the lowest beam power. It is worth noting that the percentage of delivered beam increased as time went on. Typically, as the machine is tuned and operated routinely, the beam becomes more stable. Fault studies are best conducted in brief breaks during routine operations rather that turning it on and off for fault studies exclusively.

The routine survey conducted in beam line 1 was conducted with poor transmission. This was the first survey conducted after placing beam into the experimental area. It is not expected that all the values are typical for routine operations. Table VI displays the results for several locations scaled to 0.128 Watts and 1.28 Watts.

Table VI: Beam Line 1 Routine Survey

Location	Dose Rate (0.128 W) mrem/hr	Dose Rate (1.28 W) mrem/hr
East gate	2.5	25
End wall	.7c	7c
Gap over equip. door	3.6	36
Pipe penetration	3.6	36
Building gap south-west side	.7c	7c

The routine operation of beam line 2 had two locations that were higher than for beam line 1. These are shown in Table VII. The transmission was also poor during this routine survey. Again it should be noted that the delivered beam to the stop is used for scaling and the measurements include both the transport losses and the beam stop losses.

Table VII: Dose Rates Measured for Routine Operation of Beam line 2

Location	Dose rate at 0.128 W (mrem/hr)	Dose rate at 1.28W (mrem/hr)
East gate	8.0	80
Gap over concrete door	4.3	43

There is an active radiation detector near the east gate. A monitor TLD (was 72 and now is 142) and the dose history typically shows less than 40 mrem in a year. Operators must respond to the chipmunk if the dose rate is greater than 2.5 mrem/hr.

South-west Building Penetration

Routine levels along the wall are detectable but low. Minor amounts of radiation can leak through the shield by the I-beam from the W-plug. The area along the wall has a table that is a controlled area and a radiation materials area to work on small components from the experimental hall. The measured dose rates along the building wall are given in Table VIII.

Table VIII: Dose Rates in North Area of Control Room

location	Routine (0.128W) (mrem/hr)	Fault (0.128W) (mrem/hr)	Fault (1.28W) (mrem/hr)
I-beam	0.7c	2.2	22
Mid-point of wall	0.7c	5.8	58
End edge of wall	0.35c	7.4	74

During a fault near the building transition the point with the greatest distance from the source has the highest number. This is a result of the building structure that penetrates the concrete shield having a width of about 5-7 inches but the wall having been studded out with a width of about two feet. This change in geometry is what causes this effect. It also implies that the highest dose rates are inside the wall. The wall will be posted to ensure workers do not open it.

Miss-steering by Dipoles D2, D3, and Vertical Spectrometer Magnet.

Miss-steering by large angles was conducted with the two 20-degree transport dipoles D2 and D3 and the 90-degree vertical spectrometer magnet. Zero current and maximum current were two of the angles chosen since they are the most likely errors. The area was examined and one intermediate angle was chosen, which might challenge a specific location of the shielding. Shadow shields were added downstream of D2 and D3 with the dedicated purpose to limit faults for miss-steering. These may not have been required but it was decided to have shadow shields specifically placed for this purpose. The existing shielding distributed along the beam line may have been adequate.

The miss-steering of the dipoles caused only modest increases in the dose rates near the various weak locations. There was no detectable dose outside the end wall from miss-steering the transport dipoles except for an area outside the east end of the building, which was caused by miss-steering in beam line 1. For operations at 0.128 Watts, a dose rate of 3.6 mrem/hr is expected during a full beam fault. Levels of a few hundred micro-rem were detected for the routine operations. Elevated radiations levels were detected along the building past the concrete. This area should be enclosed in a controlled area until TLD monitor data can provide guidance on the expected yearly dose. The weakness is caused by the labyrinth which prevents sufficient shielding for a section of wall. The dose rate was smaller than that at the gate by a substantial margin. An alarming chipmunk is located at the east gate.

Other Faults

The beam was scraped in two additional locations in beam line 2. The measured dose rates at the weak locations were less than the radiation levels detected in other fault conditions.

Active Radiation Monitors and Monitor TLDs

The ATF has five active radiation monitors. These monitors are called chipmunks and are calibrated and field tested every year. The chipmunks allow the operators to actively monitor dose rates at the five locations. The operators are trained to respond to elevated levels at the chipmunks and take corresponding action. The operator actions are described in procedure PO-P-ATF-0004, http://www.bnl.gov/atf/Safety/Procedures/PO-P-ATF-0004.pdf . During the fault studies the chipmunks were not recorded. The chipmunk data is not stored in a database but chipmunk data is recorded to the database during any alarm condition (if levels exceed 2.5 mrem/hr).

Four of the five chipmunks are located in particular weak locations. These locations are the east gate, on top of D2 in the experimental hall, at the front of the CO2 room, on top-side shielding between the third and fourth penetration in the Linac west hallway. The hallway chipmunk should be checked to see if it is in the most effective location, as it is substantially above beam height. The selected locations of the chipmunks clearly indicates weak locations were recognized and action taken to provide active monitoring.

There are eleven monitor TLDs that are used to monitor the integrated neutron and gamma radiation on a quarterly basis. The number scheme has recently changed and Figures one and two below show the locations. In recent years the TLDs are consistent with zero elevated gamma radiation except the one near the east gate (about 30 mrad/yr), the CO2 room (about 10 mrad/yr), and the north end of the west hallway (about 10 mrad/yr). Many of the years displayed in Table 2 of the ATF SAD do not have the background subtracted. This mistakenly gives the impressions that the side walls typically have 50-60 mrads/yr of gamma dose. The average yearly background gamma dose for 2005-2010 is 54 mrad.

The neutron doses measured on the monitor TLDs are typically less than 10 mrem/yr. A few exceptions are the TLD at the end of the mezzanine (19mrem/yr), the north end of the hallway (250 mrem/yr last two years) and the TLD near the east gate (24 mrem/yr last year).

The TLD monitor data coupled with the fault studies show the shielding design was sound and has low photon and neutron leakage. Only a few limited locations seem to have any discernible dose for past operation.

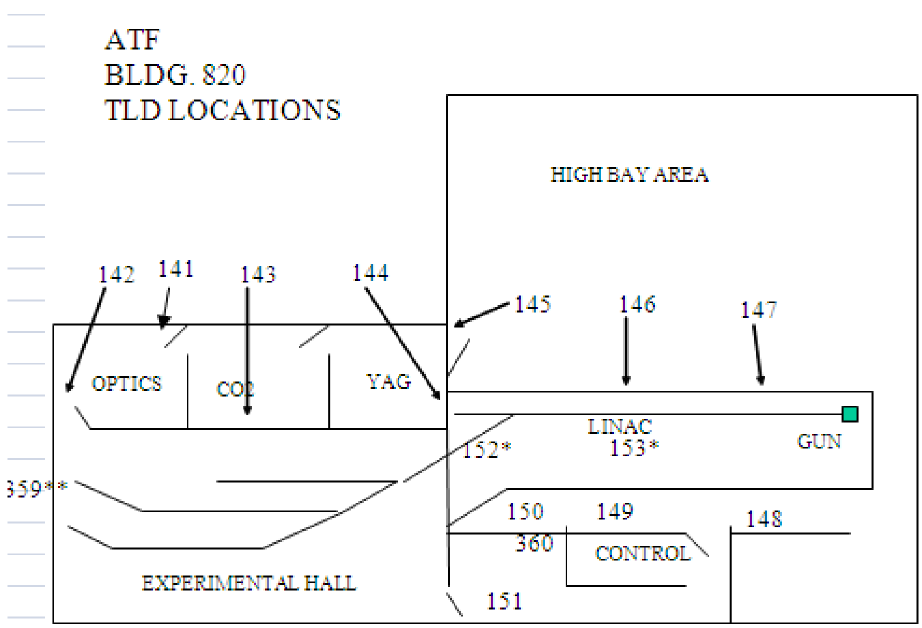

Figure 1: Monitor TLD locations for 2011.

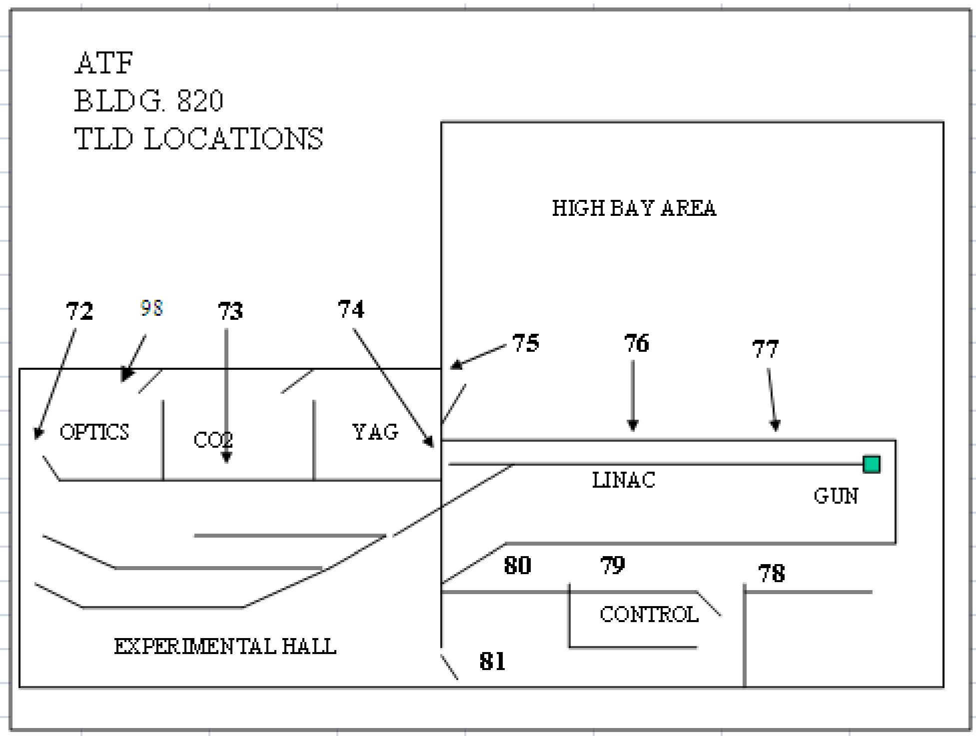

Figure 2: Monitor TLD locations for 1998-2010.